Potential of Terrestrial Laser Scanner techniques and Geographic Information System for Concrete Dam Monitoring

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***Abstract*— *Monitoring the deformation of concrete dams is of vital importance for avoiding catastrophic loss of infrastructure and life. However, dams monitoring still being a challenging task. In the last years, significant efforts have been undertaken by international researchers to find an efficient way for deformation monitoring of this kind of structures. This paper aims threefold. Firstly, to present different methods and means using for monitoring concrete dams. Secondly, to identify the opportunities that could potentially improve the inspections and the monitoring behavior using Terrestrial Laser Scanner (TLS) techniques. Based on a dense and accurate 3D point cloud and images provided by TLS, it is possible to detect vertical and horizontal deformations and all pathologies affecting the dam safety, such as cracks. Thirdly, to show the importance of Geographic Information System (GIS) that allows managing a 3D database, spatial analysis of all external pathologies, planning with developing a suitable monitoring plan and decision making. In this paper, it is clearly highlighted the importance of using TLS and GIS in order to develop an effective dam monitoring process that can help identify structural problems before they become critical and endanger public safety.*

***Keywords*— Concrete dam, GIS, Monitoring, TLS.**

I. INTRODUCTION

In the field of civil engineering, dams have always been considered as specific engineering structures [1]. However, as all concrete structure, aging is a problem that concerns more and more structures in use [2]. This mechanism is an important concern for the operator of this type of structure because it causes damage [3] that can reduce the life span and affect the stability of the structure [4]. For avoiding catastrophic loss of infrastructure and life, dams monitoring is of vital importance [5]. It is based, inter alia, on the instrumentation whose efficiency is related to two factors: the early detection of anomalies and the measures transmission speed [6]. Corollary to the security process, it sets in conjunction visual inspection, non-destructive auscultation (geophysics methods) and instrumentation, that is, the installation of measuring instruments outside and inside the structure [7].

In the last years, significant efforts have been undertaken by international researchers to find an efficient way for deformation monitoring of this structures. Measuring and monitoring deformations of these structures still being a challenging task. Several techniques and means are used for dams monitoring such as geodesy, geomatics, sensor technology, remote sensing, photogrammetry and Multi Temporal Interferometry (MTI) techniques [8],[9],[10] . However such technique, though undeniably very accurate and reliable, has disadvantages.

Also, GIS is used extensively in the fields of architecture and civil engineering for monitoring engineering structures but rarely for monitoring dams. Even commercial solutions available in the GIS market are pretty poor in 3D.

This paper aims to introduce a new method based on TLS and GIS to monitor, periodically in 3D, the behavior and the evolution of external pathologies, in particular cracks affecting downstream of a dam and be able to draw good interpretations by making interventions in time. This solution is based on a 3D survey obtained by high precision TLS carried out in 2012 and 2016 on a vault dam named Asfalou, located in Morocco at 65km from the city of Taounat.

II. PROBLEMATIC

The deformation monitoring schemes may vary greatly from country to country. Accelerometers, acoustic emissions, concrete resistivity, digital image correlation, fiber optic sensors and Global Navigation Satellite Systems (GNSS), laser alignment, total station and inverse plummet, are employed for dam deformation monitoring [11].

In recent years, nondestructive investigations on building and civil infrastructures are increasingly improving [12],[13], [14], but, the literature on the applicability of TLS techniques and GIS to monitor periodically the concrete dam craks is still very

limited. And particularly, in Morocco, the visual inspection methods of all issues that may affect the concrete dams still being traditional and provide only punctual information.

In this paper, we focus on the inspection of cracks affecting the downstream face of the arch dam named Asfalou, well as vertical and horizontal displacements of the vault using TLS and GIS techniques. These techniques offer the possibility of quickly investigating all displacements and pathologies affecting the dam without contact or need of destructive actions. Therefore, this paper is organised as follows:

- The description of the Dam Asfalou;
- The different methods and materials using to monitor arch dams;
- The TLS survey design and the conception of GIS application.
- Results and discussions.

III. THE OBJECTIVES

GIS was designed to explore and understand the spatial distribution of data from different scientific disciplines, such as ecology, geology or demography [15]. They allow the visualization of complex 2D and 3D variables. In the GIS software, vector shapes can also be described qualitatively [16].

Likewise, in recent decades, the laser scanning technique based on the use of TLS has improved [17] and become a complementary technique to measure with high precision the displacements of infrastructure [18] and without physical contact with the object [19]. It should be noted that the exploitation of the high redundancy of data, provided in few minutes with very high precision tools by TLS [20] ;[21] ; [22] ; [23] ; [24], is a key to getting good performances of 3D measurement of deformations [25].

So the issue that arises is how can we use a 3D point cloud from a TLS and use GIS to present the history and the evolution of pathologies in particular cracks affecting a downstream dam and be able to draw good interpretations by making interventions in time.

This is the objective of this research. It aims the establishment of a innovative 3D GIS application that can provide continuous and careful monitoring of pathologies affecting the safety of Asfalou dam, such as cracks. The application is based on a dense and accurate 3D point cloud provided by TLS, of the studied scene enjoying the real properties and characteristics of the scanned object such as coordinates (X, Y, Z) and intensity.

This application is designed to provide the user with a tool to help in planning and decision that supports two major features: a part of the overall mapping containing all interaction tools with the map and a part devoted to spatial queries to search for cracks and conducting a diachronic study of their evolution. It allows also:

- Creation of a database for Asfalou dam anomalies;
- Management, 3D visualization, and update of the dam data;
- General mapping that contains all interaction tools with the map;
- Implementation of spatial queries;
- Generation of thematic maps;
- Computerization of regulatory data on dams to facilitate their exploitation
- Decision making and planning

IV. PRESENTATION OF THE EXPERIMENTATION DAM

The dam of experimentation is named Asfalou. It’s an arch dam, considering the rocky nature of the foundation and the particularly enclosed topography of the valley. It is located on Asfalou River, tributary left bank of River Ouergha, 65 km from the city of Taounate and 155 km from the city of Fez. It was put into water in December 1999. Its characteristics, according to the Hydraulic Department of the Rabat Direction, are summarized in the following table:

Maximum height on foundation	107.00 m
Peak width	2.70 m
Crest length	150.00 m
Volume of the dam	81 000 m³
Coronation level	752.00m NGM[1]
Normal holding level	745.00m NGM
Higher water level	751.50 NGM
Volume at normal level	317.00 hm³
Surface at normal level	911.00 ha

Also, the hydrological characteristics of this structure are as follow:

Watershed	560 km²
Level Average	1198 NGM
Rainfall Average	757 mm
Annual flow Average	4.9 m³/s
Annual contribution Average	154 Mm³
Project flood (1 / 10,000)	3000 m³/s
Floodlight	300 m³/s
Solid inputs	1.21 10^6 t/an

In this paper, we are interested to this dam for several reasons:

- An important dam designed to enhance the security of Al Wahda dam considered one of the largest dams in Morocco, protecting against siltation.
- It meets other purposes including irrigation, power generation and flood control.
- It is characterized by the complexity of its geometry and the aggressiveness of the environment.
- It is a double curvature arch dam with a significant height. It has a narrow valley and is based on a rocky site, which makes access difficult.
- It undergoes a significant hydrostatic pressure on the upstream face and presents alarming cracks on the downstream face.

V. MATERIALS AND METHOD

5.1 Traditional method

In Morocco, monitoring is achieved by traditional method. In fact, the visual evaluation is used by inspectors as the primary tool within the scope of current practices for concrete dam's inspection and condition assessment. And, the monitoring of Asfalou dam behavior is achieved by a number of traditional instruments that are installed.

TABLE1

BELOW PRESENTS THE LIST OF THE PRINCIPAL INSTRUMENTS THAT ARE APPLICABLE IN THIS BROAD FIELD[7].

Instrument	Measured parameters
Cameras system	Tele-photography
Topographic instruments (Total station T3 and level N3)	Horizontal and vertical displacements of pillars and
Direct pendulum, inverted pendulum	Rotation and horizontal movements
Drilling extensometer, communicating vase	Vertical displacements
Fissurometer	Opening joint (surface or buried)
Strain gauge	Unit deformation of the concrete structure
Thermometer	Measures of internal and ambient temperature
Piezometers, pressure sensor	Deputy pressures
Inclinometer	Rotation
Float	Water level of the reservoir and downstream water level
Accelerometer	Acceleration (earthquakes)

[1] NGM : GENERAL LEVEL OF MOROCCO

Currently, to monitor the development of cracks, they are identified by witnesses glass (Fig.1) or paint (Fig.2) and numbered.

FIGURE1: GLASS WITNESSES

FIGURE2: PAINT WITNESSES

This method is effective in how quickly it detects any development because the witness glass breaks at the opening of the crack. However, if one of the glasses is not well bonded, it risks that the crack can develop without being able to detect.

As for monitoring the behavior of the joints between the blocks, a system Vinchon (Fig.3) is installed on each joint, and measures are regularly taken by inspectors of the dam.

FIGURE 3: VINCHON ON JOINT

The cracks are represented on a manual sketch (Fig.4) which unfortunately can’t cover the entire surface of the face of the dam due to its size and complexity of its geometry and the inaccessibility of some cracks that can’t be detected in time.

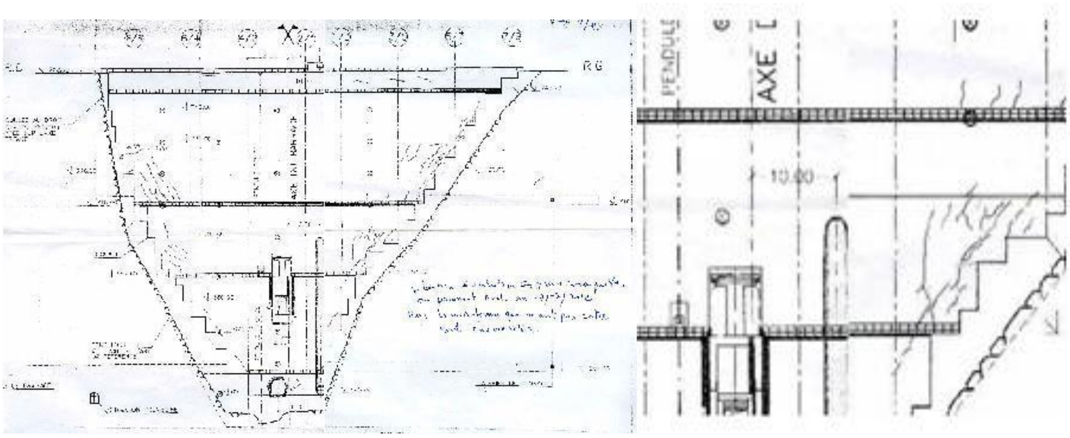


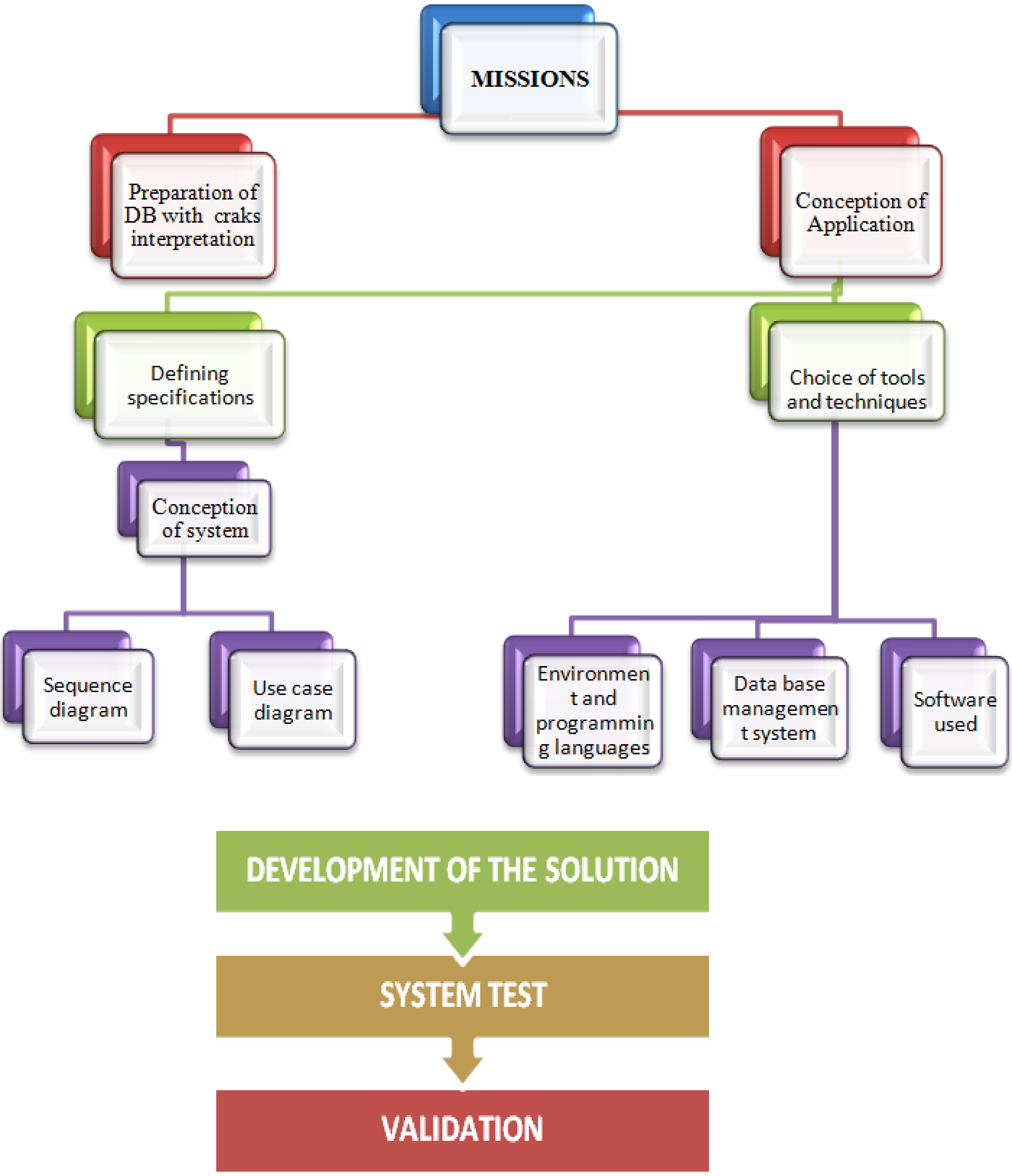
FIGURE 4: CRAKS SKETCH

5.2 New method

To overcome these gaps and respond effectively to the objectives, we propose in our study a method based on laser scanner 3D (TLS) and GIS that integrate also new 3D measurement technologies and the most powerful IT tools.

For this study, two major tasks were performed:

- The preparation of the database with 3D modeling and digitalization of cracks on two topographic surveys conducted by TLS for two thermally different periods (March-June 2012).
- The design of the GIS application including the different steps and tasks performed, since the study of needs to test and validation of the application. This is shown in the diagramme below.



5.3 Used materials:

In the field, we used a terrestrial laser scanner C10 and a powerful 32 GB computer that facilitates the manipulation and visualization of a database of millions of 3D points.

According to the experimental study carried out by Barras et al in 2013 and K. AIT EL KADI in 2016, the most precise scanner is C10 laser scanner (Table2) [26], [27].

TABLE 2
LASER SCANNER ACCURACY ACCORDING TO DISTANCE

Distance (m)	Scanner C10	HDS 6200	Focus	VZ-400
	Leica (mm)	Leica (mm)	Faro (mm)	Reigl (mm)
10	6	5	7	3
50	6	14	20	15
75	15	19	28	22
120	29	-	42	36
200	52	-	-	60
300	82	-	-	90

VI. SOFTWARE AND DEVELOPMENT LANGUAGES

This application is developed under the Visual Studio 2010 environment with the languages C # and UML. It's based on PostgreSQL for database management together with the PostGIS layer. And uses ArcGIS for 3D visualization in favor of the benefits of these tools that meet our needs perfectly.

In fact, Visual Studio 2010 is a complete set of development tools. It incorporates the latest most advanced Microsoft programming languages, Visual Basic and C # to create ASP.NET Web applications, WebXML Services, desktop applications and mobile applications [28], [29].

Microsoft also introduced in Visual Studio 2010 code modeling tool, Architecture 'Layer Diagram', a perfect way to show the progress of a program and its test phases [30].

Regarding the GIS environment, we choose ESRI (Environmental Systems Research Institute) because it gives users a full range of software and services. It allows you to archive, manage, query, analyze, visualize and map all data with a spatial attribute [31]. In recent decades, ESRI developed the ArcGIS system (formerly ArcView GIS). This system is composed of different platforms that enable GIS users, whether desktop, web, or mobile, to collaborate and to share geographic information [32], [33].

VII. EXECUTION OF THIS GIS APPLICATION

The steps for the execution of this application are as follows:

7.1 Authentication

When launching the application, the home screen displays a login area allowing the user to enter his password and login for identifying himself (Figure5).

FIGURE 5: AUTHENTICATION

7.2 Home page

Once the client is authenticated, the application allows access to the first page divided into 3 parts (Fig.6): the first concerns the cartographic ribbon, the second is for requests and the third provides 3D visualization of the dam. Maximum users can quickly learn the functioning of the application using meaningful and simplified icons.

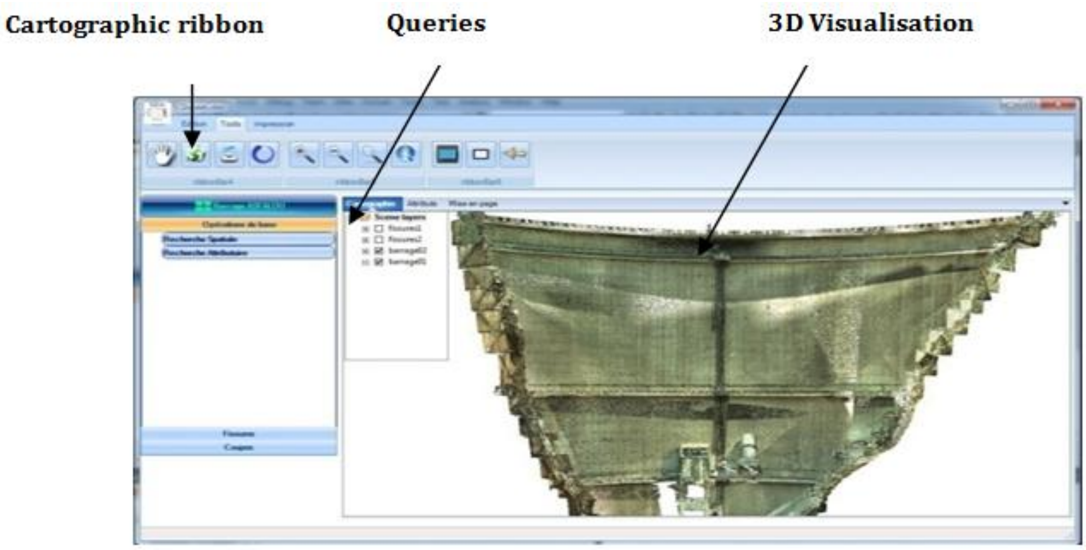


FIGURE 6: HOME PAGE

7.3 The mapping ribbon

The mapping purposes of the cracks and monitoring their evolution over time cover very diverse functions, from simple map visualization to searching information in a spatial format and attribute data.

To be actually used, the system incorporates a ribbon of classic visualization of GIS software, such as save, update, zoom (±), copy, move, show or hide selected layers….

7.4 Space research

Space research command is among daily operations that the user will need, by comparing queries between different surveys or database.

The application also provides a feature to quickly select results from a list and zoom it on the map. The implementation of this feature allows the user to print the results on paper of all or any area of the dam (Fig.7).

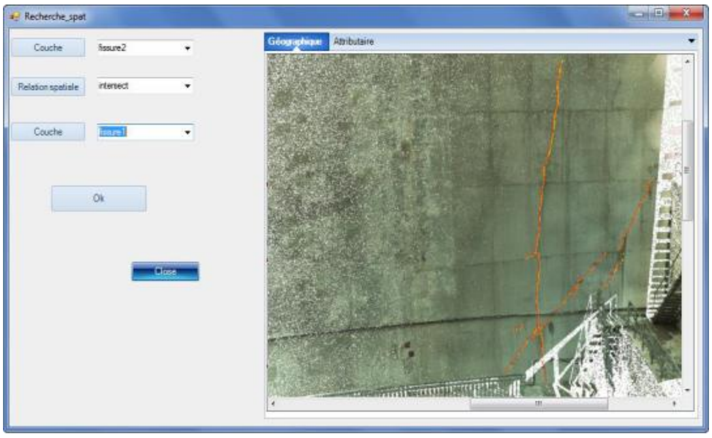


FIGURE 7: SPACE RESEARCH

7.5 Attribute Search

This form of queries allows to (Fig.8):

- Select the layer of cracks, corresponding to each period of the survey
- View all the attributes of the layer in the attribute field;
- Choose the field, the operation and the criteria to respond to the request;
- Combine between queries using Or / and logic.

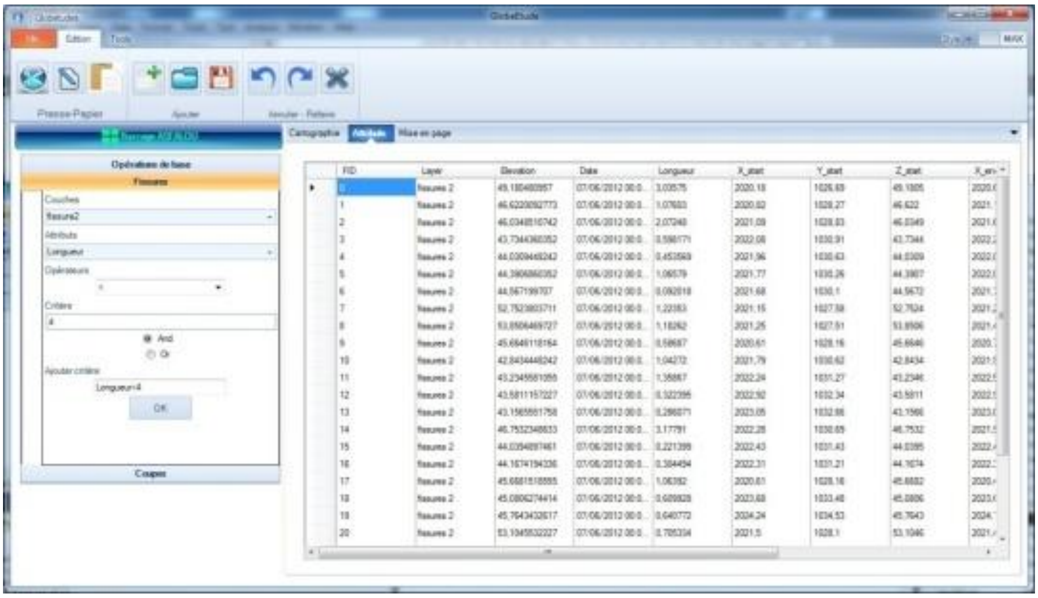


FIGURE 8: ATTRIBUTE SEARCH

7.6 Graphic selection cracks

Developed pop-ups allow the user to display features of cracks such as the dates of the survey, their numbers, their 3D coordinates, and their lengths for each period of the survey (Fig.9). This option is a quick function that facilitates to the user precise monitoring and updating of its database and so having a general idea about the appearance of new cracks.

FIGURE 9: GRAPHIC SELECTION CRACKS

7.7 Check of cracks

This option is very important because it provides the user with the actual state of the dam at the time the survey without returning there.

In fact, the user can redisplay 3D movement, from each station of the survey as it is on field, the entire face of the dam and check if there are missed cracks (Fig.10).

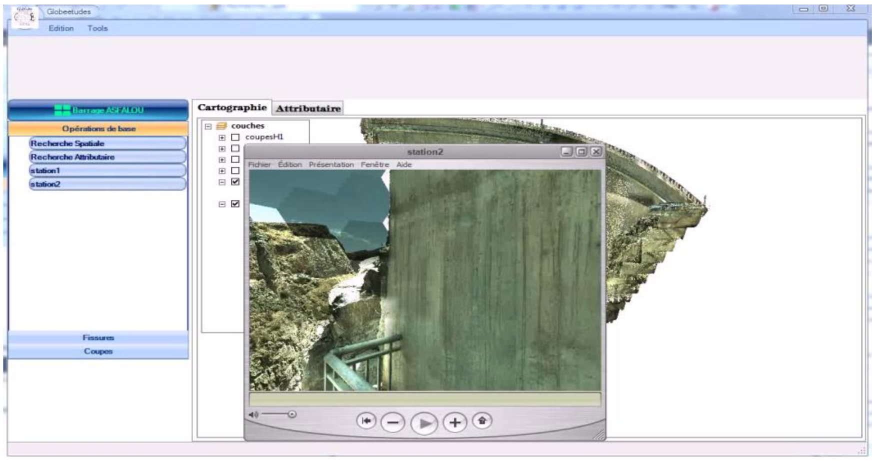


FIGURE 10: ACTUAL DAM VIDEO

VIII. RESULTS AND DISCUSSIONS

Conventional methods allow us to have a sketch representing the different cracks as their result. Unfortunately, this representation may not cover the entire area given the size and complexity of the structure. Also, it does not form a faithful witness because the inspector for monitoring the structure can, by forgetfulness or inattention, not restitute in time a newly occurred crack.

This approach allows the user to have a 3D database that is real in position and time, of the entire siding acquired without contact of the structure. The user can access at any time and recheck quantitatively and qualitatively with high accuracy, compared to the reality the various cracks, their statements and positions. Also, the operator of the structure can update it and may have later a topographic geo-referenced map in the 3D coordinate system of the dam.

In addition, it allows a win of time and cost.

IX. CONCLUSION

In conclusion, we can say that the developed solution has demonstrated its interest and relevance in the context of the management and monitoring of the evolution of the cracks that may affect the downstream face of a concrete dam. Indeed, benefiting from the characteristics of TLS and strength of GIS, the application allows:

- Capitalize the information, gather them into a single tool,
- Establish a platform for monitoring the health of the dam of Asfalou,
- Update continuously and accurately the database according to different auscultations,
- Provide a communication tool: it allows the user to view the cracks by characteristics or by adopted thresholds.
- Plan and make fair and right decisions.
- And finally, it saves time and cost.

ACKNOWLEDGEMENTS

We wish to thank the managers of both offices of topography and engineering “GLOBETUDES” and “CT MOUATASSIM” for providing TLS C10 to scan the arch dam Asfalou. And we extend our gratitude to everyone involved with collecting data in the dam.

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